PERT/CPM AND SUPPLEMENTARY ANALYTICAL TECHNIQUES: AN ANALYSIS OF AEROSPACE USAGE

THESIS

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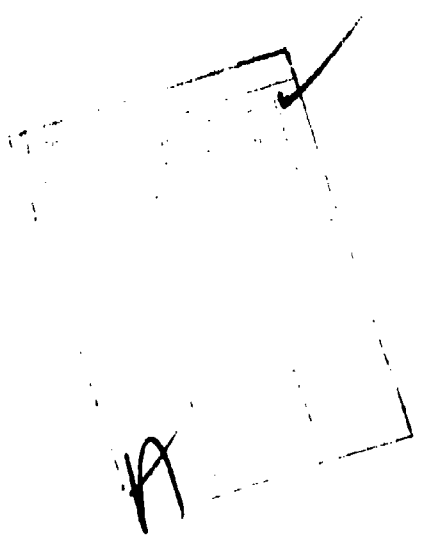
Preface

This thesis presents the results of 114 contacts made with managers in the aerospace industry, both government and civilian. The purpose of this document is to analyze the data gathered in the course of these contacts, so as to obtain a better understanding of the current applications of PERT/CPM, CDA and CRA. By this understanding, I hope to be able to influence managers in their future use of these techniques.

I am very grateful to the many individuals, in the Air Force and private industry, who unselfishly gave me information about the management techniques being used in their organizations.

I would also like to thank Major Edward J. Dunne, my advisor, for his support and guidance throughout this research effort. Without his advice, this thesis would not exist today.

Finally, I would like to acknowledge the invaluable assistance and patient understanding of my wife, Julie, during the months devoted to the research and preparation of this thesis.



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Abstract

The rapid pace of technological progress in the last 75 years has caused the development of a number of new management tools, but perhaps the most controversial of these is network based management. Two closely related methods exist, the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). These methods are often spoken of today as one, called PERT/CPM. Two important analytical techniques often used with PERT/CPM are Cost Duration Analysis (CDA) and Critical Resource Analysis (CRA). PERT, CPM, CDA, and CRA have gone through many changes since they were develc in the late 1950's, and the current theoretical and mathematical approaches to them can be quite complex. This theory tends to dominate published material in the network management field, there being little documentation of practical applications of PERT/CPM. This disparity was investigated in the aerospace industry in this thesis.

Contacts were made with 114 organizations, 48 military and 66 private industry. Information was received from 105, and of these, 48 were using some form of PERT/CPM. In the military, 38 percent were using PERT/CPM; while in industry it was 47 percent. There was a significant discrepancy in the experience levels between Air Force and industry, with the industry having considerably more experience. The use rates for CDA and CRA were found to be quite low, with only 9.3 percent and 7 percent, respectively, of current PERT/CPM users reporting the use of these techniques. Individuals interviewed were asked to evaluate CDA

and CRA, and it was found that the most often mentioned reasons for not using CDA and CRA were their complexity and cost.

PERT/CPM AND SUPPLEMENTARY ANALYTICAL TECHNIQUES:

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I Introduction

Background

The history of management contains records of the use of many various types of tools and techniques. The advent of what has been called scientific management in the early 1900's brought about a trend toward complex managerial systems, and this trend continues today. The rapid pace of technological progress in the last 75 years has spawned the development of a number of very interesting managerial tools, and one of the most controversial of these is network based management. This management tool can be thought of as two very closely related methods, the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). Each of these was developed by a different group, to be used on different types of projects, but they still have a considerable amount in common. Through the 20 years or so since they were conceived, these methods have undergone evolutionary changes, additions, and deletions. There are many supplemental analytical methods which have been used with PERT and CPM, but the two most common are Cost Duration Analysis (CDA) and Critical Resource Analysis (CRA). These two analytical techniques will be examined in detail in this paper, but some definition of terms is first required.

Terminology

PERT and CPM originated as separate methods, but are now often thought of as the same thing. In this paper, when one or the other is used it is meant that method specifically; when PERT/CPM is used, it is meant both methods taken together as a generic set of networking methods. The reader is assumed to have a basic familiarity with PERT/CPM, and if this is not the case the reader is referred to an introductory text on PERT/CPM (Ref 6, 13, 41).

PERT: A PERT network consists of a group of events or activities usually represented by circles and arrows linked together in a manner which represents the project to be completed. Most often constructed as an Activity-on-Arc (or Arrow) network (A-on-A) Three time estimates are used, pessimistic, most likely, and optimistic; this allows statistical information to be calculated, such as the probability of completing the project on time.

CPM: This technique is similar to PERT in appearance, but the circles or nodes usually represent the activities, hence it is often called Activity-on-Node (A-on-N). Only one time estimate is used for each activity, which is simpler, but allows for no statistical calculations. As a result, CPM networks are often referred to as deterministic, as opposed to a PERT network which is probabilistic.

Cost Duration Analysis (CDA). This is a method of economic analysis which can be applied to PERT/CPM networks. Each activity in a network is assigned a direct cost for its normal completion time, and then is assigned other values of direct cost (usually

higher) for various shorter completion times, down to a time which is believed to be the shortest feasible activity completion time. Using these direct cost-time relationships for each activity in a network, CDA progressively decreases total project completion time in such a manner that the project direct cost is increased the least possible amount. This project direct cost-time relationship can be combined with indirect costs, and other data such as bonuses for early completion and penalties for late completion. This then allows further economic analysis which can indicate a project completion time which is optimal in terms of minimum total project cost.

CDA has also been called other names: time-cost trade-off analysis; cost optimization; schedule compression; synthesis.

Critical Resource Analysis (CRA). This is an analytical technique used with PERT/CPM networks which have one or more resources that are available only in limited quantity. When a resource is required for the completion of several activities which may be scheduled at the same time, this technique is used to develop a schedule or sequence for the employment of these limited resources. These schedules or sequences of employment allow the project to be completed in either the desired time, or if that is not possible, in the shortest feasible time greater than the desired time.

In the first case, where it is possible to schedule resources into the network without modifying it or lengthening it, the method is called resource leveling. In the second case, when this is not

possible and the network must be modified in some way, the method is called resource scheduling.

Examples of resources which are often available only in fixed number, and hence could become critical resources are: key supervisory personnel, special machinery or equipment, storage or working space, and transportation equipment or vehicles.

Research Objectives

PERT/CPM networking techniques, cost duration analysis, and critical resource analysis are often major topical areas in many management, Operations Research (OR), and Industrial Engineering texts and periodicals (Ref 6, 11, 12, 20, 24). The overall objective of this effort is to determine the extent, type, and manner in which these network management techniques are currently being used in aerospace related activities in government and industry. Subsidiary to this general theme are specific objectives to be achieved in support of the overall effort.

PERT/CPM Usage. At one time, use of PERT was mandatory on all major DOD acquisition contracts. Since that time, the use of PERT and CPM seems to have dwindled considerably (Ref 11, 14). An objective of this research is to determine how much PERT/CPM is being used today in major aerospace acquisition programs, both by contractors and by the Air Force. Additionally, in what situations, if any, is PERT/CPM used more often (i.e.: research, development, pre-production, mass production, quality assurance, etc.).

The above specific objectives deal with factual use of PERT/CPM. Also to be investigated is the opinion of PERT/CPM users as to the

methods' usefulness and desirability versus other contemporary management tools. These data will be recognized for what they are - opinion, and will be treated accordingly.

CDA/CRA Usage. These analytical techniques have often been recommended in the literature as important tools to augment PERT/CPM networks. An objective to this study is to determine to what extent CDA/CRA is being employed by users of PERT/CPM networks. The reasons for managers' use or non-use of CDA/CRA techniques is also to be investigated. These reasons, when compared to the theoretical literature, may have important implications for future research in the area. If managers are not using CDA/CRA, is it because they have tried it and found it unsuitable, or have they relied on negative reports of others, or are they uninformed of the potential usefulness of these techniques? These are all questions addressed by this study.

Methodology

In order to accomplish the objectives of the research, a search of the literature was necessary, and data on PERT/CPM usage had to be gathered and analyzed.

Literature Search. In order to properly place today's use of PERT/CPM and CDA/CRA in perspective, a knowledge of the history of the techniques is necessary. To meet this end, a concentrated search was made of the available literature. Emphasis was put on historical development of CDA and CRA, and on the theory as currently contained in the literature. Historical information on PERT/CPM was also gathered in the course of the research. Much of the material concerning early PERT

are DOD documents, therefore extensive use of the Defense Documentation Center (DDC) and the Defense Logistics Studies Information Exchange (DLSIE) was made. Prior theses and dissertations, at this institution and elsewhere, were examined. These papers were most helpful, often saving more extensive background investigation.

Interviews. The actual data about usage of network management techniques come from interviews with persons in both the Air Force and industry. A survey could have been used, but a survey of non-government employees was ruled out by Air Force, DOD, and Office of the Management and Budget (OMB) policies. Only a very limited number of surveys of this type are allowed annually to be done by government employees, and the approval necessary could not be obtained. For this reason, interviews of industry representatives was chosen as the next best alternative method. For consistency of analysis, interviews of Air Force personnel were also used.

Approximately 100 knowledgeable individuals were contacted in the Air Force and industry. A knowledgeable individual is defined as one who has information, from personal or direct supervisory experience, of the use or non-use of PERT/CPM and CDA/CRA by that individual's organization. To get to that person often required contacting two or three others in the same organization, since special attention was given to contacting the person most knowledgeable about PERT/CPM in each organization. For a list of organizations contacted, see Appendix A; for a list of persons interviewed, see Appendix B. Some interviews were conducted in person, while some were conducted by telephone, depending on the amount of information believed at the time to be available, and

on the location of the individual. Most industrial interviews were by telephone, while Air Force interviews were about 50 percent by telephone. Regardless of whether telephone or personal, each interview was structured the same as much as possible. Questions were formulated and answers recorded using the format shown in Appendix C. It was often necessary to define CDA and CRA and occasionally PERT/CPM. This was done using slightly modified versions of the definitions presented previously in this chapter.

Sources for persons to interview were many and varied. At Wright-Patterson AFB, the Aeronautical Systems Division (ASD) computer center personnel were helpful in pinpointing PERT/CPM users. Other sources were the writer's personal knowledge, telephone directories, organizational charts, and word of mouth from other PERT/CPM users. In industry, sources were Dayton Chamber of Commerce publications, magazines, advertising circulars, telephone directories, and references from other PERT/CPM users. A word of explanation is necessary about the apparent duplication of some organizations in Appendix A. Some organizations (Air Force and industry) have quite centralized control functions, so that one office has knowledge of the workings of many projects, and a knowledgeable individual in that office was the only contact necessary in that organization. Other organizations are quite rigidly divided by project or division, and are responsible to the parent organization only as a cost center. In this case, a knowledgeable individual had to be contacted in each responsibility center. In a decentralized organization, on occasion, a person could be found who had been in the company for many years and knew the workings of many areas.

After the detailed questions concerning CDA and CRA, additional comments were solicited regarding PERT/CPM, and these were recorded as accurately as possible. These comments were helpful in defining attitudes and other subjective evaluations of the data by the interviewer. These interview evaluations will be discussed later.

There appear to be some distinct advantages to interviewing versus surveying in a research project such as this. One advantage is the ability of the interviewer to draw out a reticent participant. Questions in a survey may not be interpreted in the same manner by everyone, but in an interview they can be re-phrased. Another advantage is the ability to contact the one person (or persons) in an organization who have the most knowledge about the subject. The most obvious advantage is the number of returns. Survey return rates can be quite low, on the order of 20 to 30 percent. There are some disadvantages to interviewing as well, the largest being time and work. Even by telephone, interviewing almost 60 people is time consuming, as is getting in touch with the right person. Another disadvantage is interviewer bias. Leading questions and interviewer reactions were controlled to some degree with the structured format that was used.

Analysis of Data. When all interviews were completed, the answers were coded and transferred to computer cards. The design of the format for the transfer of data was done after most of the interviews were complete, and thus it was able to accommodate pertinent comments outside the structure of the interview format. The data was analyzed using the facilities of the ASD computer center, with a remote batch terminal from the Air Force Institute of Technology, School of Engineering. The

ASD/AFIT system consists of a CDC 6613 and a CDC CYBER 74 operating system and peripherals. The Statistical Package for the Social Sciences (SPSS) is a set of programs available, some of which were used for this analysis.

Data was analyzed by percentages in various categories, and then broken down further by cross-tabulation techniques. Frequency of responses, as well as numbers of responses are presented in the analysis sections later. List-wise and case-wise deletions of missing data were both used, whichever seemed most appropriate to the goal of maintaining objectivity, while maintaining a significant number of data points.

Scope and Limitations

The enormous number of uses being made today of PERT/CPM precluded a detailed study of all aspects of their use. This research project has examined the uses to which PERT/CPM have been put, and are being put today in the aerospace acquisition field. This field is not limited to national defense acquisition, since it includes data from civilian aerospace organizations not on military contracts. The aerospace field includes both aeronautics (i.e.: aircraft and systems) and astronautics (spacecraft and systems).

There are other types of networks in use today other than PERT/CPM type networks, such as precedence networks used in Line-of-Balance (LOB) systems, and a network used by the Air Force in its Logistics Composite Model. These networks are mentioned as necessary to make points in this report, but are not specifically examined in detail.

The use of CPM is fairly common in the construction industry, especially for large, complex jobs. These applications will not be explored closely, but mentioned as necessary to contrast them with aerospace applications.

Limitations imposed on the use of surveys have been mentioned previously. Time limitations and wide geographic separation also precluded personal interviews with many more participants. Finally, time was the controlling factor of the number of interviews. The 57 interviews obtained have been assumed to be a representative cross-section of the industry and Air Force.

In this chapter, a short background of PERT/CPM has been presented as an introduction to the subject, and some basic terms have been defined. The objectives of this paper, the assumptions made, and the methodology which was used have been presented.

In Chapter II, the development of PERT, CPM, and their supplemental analyses is traced. The current theory of CDA and CRA is presented, and past application areas of PERT and CPM are identified. Chapter III is an analysis of the results of the interviews to determine the pattern of usage of PERT/CPM in the aerospace industry. Use on various types of projects will be documented, and assessments of PERT/CPM made by the respondents will be examined. Chapter IV contains the analysis of CDA and CRA usage. An examination of management perceptions of these analytical methods will be made, and the relationship of these perceptions to actual practice will be explored. In Chapter V, the literature on CDA and CRA is compared to its actual use, and conclusions are drawn about the implications of this on the future manager.

II Historical and Theoretical Perspectives

Before examining the uses being made today of PERT/CPM this chapter will serve as review of the development of PERT and CPM, and of the current state of theory about CDA and CRA. Although PERT and CPM had origins in different types of application areas, they have recently become thought of and spoken of as one and the same by some authors (Ref 10, 11, 12, 24). Cost and resource analyses of these networks have likewise been recently lumped together, despite earlier distinctions. These early differences and the recent interweaving of concepts and techniques is significant, and the tracing of these events will build a necessary background against which today's techniques may be viewed.

Development of CPM

CPM was probably the first networking technique developed to be used as a management tool. The E. I. DuPont de Nemours & Company began development of the method in 1952, and by 1955 the basic concepts of Critical Path Scheduling (Ref 14:16) were outlined. In 1956 and 1957 further work was done, including the use of computer programs to test and demonstrate the technique. The development effort was a joint project of DuPont and the Remington Rand Division of Sperry Rand Corporation. James E. Kelley, Jr. was the principle developer of the model and the mathematical technique, while he was head of Remington Rand's UNIVAC Applications Research Center. Morgan Walker, the DuPont engineer who worked with Kelley, headed DuPont's Systems Engineering Development

Group. These two men pioneered the development of CPM, and continued for years afterward to be the authorities on it.

The first large scale use of this new procedure was on the periodic overhauls of a chemical plant in Louisville, Kentucky. The problem at the plant was the downtime lost during overhaul, since a complete shutdown was necessary for safety reasons. Using Critical Path Scheduling, DuPont engineers were able to cut downtime from 125 hours to 93 hours, and anticipated cutting downtime further through the use of CDA (Ref 1:61). Even at this time, in 1959, Cost Analysis was a part of this networking method.

Cost Analysis. Kelley and Walker's early version of CPM contained provisions for cost analysis which differ in no basic way from those being used today. This concept of Cost Duration Analysis (CDA) was well established as an integral part of CPM by Kelley and Walker, and was considered by some as more important than later statistical analysis introduced in PERT (Ref 1:66). The methodology used at that time by Kelley was the primal-dual algorithm, a special type of parametric linear program (Ref 17:296). The primal-dual algorithm has undergone some evolutionary sophistication since then, but remains the basis of many CDA methods (Ref 10:26; 12:61). A later section in this chapter will deal with the current theory of CDA.

Resource Analysis. The basic foundations for CRA were laid by Kelley and Walker, but the technique was not developed as extensively or as early as CDA was developed. The idea that certain resources may be in short supply, and hence may control the completion time of the network was expressed by a number of authors in this early time

period (Ref 1, 4, 17, 41). The first reduction of this concept to practice probably occurred in the 1960-1962 time frame in connection with the then rapidly developing CPM technique. Although no specific literature on its earlier development could be found, in 1961 Kelley proposed two heuristic rules for its solution (Ref 20:352-354).

During the years 1957-1958 a parallel effort at developing a network management technique was taking place which, though not an outgrowth of CPM, did have its genesis in some of the earliest CPM development.

Development of PERT

In early 1957, the Navy started development of the Polaris or Fleet Ballistic Missile (FBM) weapon system. The Special Projects Office for Polaris concluded that existing management systems were inadequate to handle the 250 major contractors and 9000 subcontractors involved in the program (Ref 14:14). In January 1958, a special study group was formed of individuals from Booz, Allen, and Hamilton (a management consulting firm), Lockheed's Missile System Division, and the Navy's Special Projects Office. The development of CPM had not been overlooked by the Navy, and DuPont had briefed the Navy about CPM in mid-1957 (Ref 14:17). In developing PERT, however, the Navy carried on where DuPont had left off, and developed PERT to fit the needs of the FBM Program.

These needs were for a technique which could handle the uncertainty which existed in the program. Efforts of this type and size had never before been attempted, so single time estimates for activities were

rejected in favor of three time estimates for each activity. This permitted the use of statistical analyses on the network, such as the standard deviation of the time estimates, and the probability of on-time completion. The result of this development effort was PERT, at that time called the Program Evaluation Research Task (Ref 30, 31). The Summary Report Phase 2 of the implementation of PERT at the Strategic Systems Project Office, dated September 1958, makes no mention of CDA or CRA (Ref 31). Nor is any mention made of CDA or CRA in an article about PERT by D. G. Malcolm et al, which was received by the publishers in April 1959 (Ref 41).

PERT in the DOD. When the Navy's successful use of PERT became known, the use of PERT in the military services and NASA spread very quickly. By 1960, the Air Force had developed the Program Evaluation Procedure (PEP), and its use was soon widespread in the Air Research and Development Command, which became the Air Force Systems Command (AFSC) in 1961 (Ref 14:22). Also in 1961, the term PEP was replaced by PERT, the two being so similar only a name change was needed in the standardization efforts then underway. There were many PERT coordinating councils and groups in the DOD, all trying to make PERT very set and regimented (Ref 14:23-26). By April 1964, the Air Force had published a series of five manuals called USAF PERT (Ref 38-42). These manuals, which included PERT/COST and all necessary computer system information, were the definitive word on PERT at the time, and remain valuable references today. Also, by mid-1964, PERT and PERT/COST were mandatory for use on all major defense acquisition contracts, and all major program offices in all services were using it (Ref 14:29).

For a detailed historical account of this period, and the use up to 1974 of PERT in the Air Force, see Ewart and Nanney (Ref 14). There has been speculation that PERT has fallen out of favor in the Air Force, but some authors believe that it has merely found its proper place (Ref 11:49; 14:92; 24:82).

PERT/COST. Management responsibility is often thought of as being divided into three areas: time, cost, and performance (Ref 34:1). PERT is a planning and scheduling tool useful only in relating time and performance, not in the area of cost control. An extension of PERT into the area of costs was conceived by its developers (Ref 4:17). The actual development of PERT/COST was done by Management Systems Inc. during late 1961 and early 1962, while under contract to the Department of Defense (Ref 14:42). The PERT/CPM approach focuses on a Work Breakdown Structure (WBS), rather than on activity networks as in the basic PERT and CPM techniques. The WBS divides into Work Packages, which at that time were of about three months duration and represented a maximum of $100,000 (Ref 9:29). These Work Packages were organized by project, and cut across the functional lines of traditional cost accounting systems (Ref 34:2). In practice, PERT/COST reports were comparisons among actual, estimated and budgeted costs, and between actual and estimated times for each Work Package (Ref 14:43). Despite the fundamental differences which existed between PERT and PERT/COST, they were often used together and became closely associated in the minds of many people. This relationship resulted in CDA and CRA being associated by some people with PERT/COST, when in fact they were used with PERT networks.

The PERT Supplements. CDA and CRA were sometimes presented as optional analyses to be used with PERT if desired, and were often identified as "PERT Supplements" (Ref 9:104; 15:39-40; 36:22-25). There were two "PERT Supplements" identified in these references, "Time-Cost Option Procedure" and "Resource Allocation Procedure." These procedures amounted to very simplistic CDA and CRA, respectively. The Time-Cost Option Procedure did not involve a true optimization of time versus cost, but merely construction of various sub-optimal plans, the choice of which to use being left to the manager. Essentially, this was satisficing rather than optimizing (Ref 9:104). The Resource Allocation Procedure similarly was not an optimization procedure, but merely a heuristic process, the details of which were left up to the manager. These "PERT Supplements" were not part of the development of CDA and CRA, but merely off-shoots, since CDA and CRA (in connection with CPM) had at that time reached a greater level of sophistication (Ref 17:296; 20:347). The blending and interweaving of concepts at this time resulted in some confusion. For example, the author of an instructional book on PERT called CPM a "nonmilitary PERT/COST system," which it certainly is not. The unsophistication of the Time-Cost Option Procedure was short lived. In 1965, another supplement to PERT was proposed called Schedule Compression (SC). This analytical technique was similar to CDA as practiced in CPM, but had the additional probabilistic features of PERT. It relied on the use of expected value techniques and statistical analyses to find an optimal time-cost tradeoff (Ref 15:49). Other more sophisticated methods of CDA were subsequently developed wherein PERT was cited as a network suitable for CDA

techniques (Ref 25:1). In recent years, other CDA techniques have also been advanced for use with PERT networks (Ref 3:2; 35:55). These CDA techniques were proposals only, and their actual application, if any, is unknown. They were cited here to show that, in theory at least, CDA is also considered a part of PERT.

Current Theory

There are a large number of current theoretical approaches to the solution of networks and their supplemental analyses. A detailed description of each here would be beyond the scope of this thesis, but a listing or mention of the major approaches to the problem is believed to be appropriate.

Networks. Previous sections have dealt with the two most common network management techniques, PERT and CPM. A basic knowledge of these by the reader has been assumed, and the historical development of each has been briefly outlined. There have been a number of other network techniques proposed which differ from PERT and CPM in varying degrees. Two of these techniques will be summarized here because they represent the extreme directions in which network development has gone, the simple and the complex. To add to the confusion existing already in this field regarding terminology, both of these techniques have the same acronym - SNAP. The first to be discussed is the Simplified Network Analysis Portrayal (SNAP), hereafter called Simple SNAP (Ref 5). The second to be discussed is the Stochastic Network Analysis Program (SNAP), hereafter called Stochastic SNAP (Ref 43).

The Simplified Network Analysis Portrayal (Simple SNAP) has been presented as a networking approach only slightly more complex than the

Bar or Gantt chart. Its main appeal is simplicity, which has been accomplished, in essence, by stripping away all complex time estimating and probability functions from PERT. What remains is a precedence diagram of the activities to be accomplished, showing interrelationships among activities. In practice, the author uses a diagramming technique not unlike the flow diagram which might be used by a computer programmer. The Critical Path is not explicitly identified, and yes/no decision nodes are used. The advantage of simplifying a network to this extent is that it can work where a full blown PERT/CPM could not be used. In the paper proposing this technique, the author presents case studies of offices in which it was successfully used. All other network methods had failed in these offices, presumably as a result of over-sophistication or lack of acceptance by personnel. Apparently Simple SNAP is the answer when the boss will not support a PERT/CPM effort, or the manager desires to keep the effort simple (Ref 5:18-25).

The Stochastic Network Analysis Program (Stochastic SNAP) is a complete network based management system, including provisions for costs and resources. What makes Stochastic SNAP different from PERT and CPM is that it is a stochastic simulation model. Each activity time is represented by a random variable, the distribution of which has been approximated from three time estimates (as in PERT) using a triangular probability distribution function (pdf). This triangular pdf is then mapped onto a uniform pdf, and the Monte Carlo technique is used to develop the frequency distributions (Ref 43:5; 110). That is, when the model is iterated, that is, actual network performance is simulated a number of times, the critical path and all sub-critical paths are

identified by the number of iterations on which they were critical. Stochastic SNAP has gone further toward probabilistic construction than even PERT, and is necessarily a computer based system, since the suggested number of iterations is between 100 and 250 (Ref 43:18).

Advantages of this system are in its closer-to-real-life representation of activity times, and its flexibility to perform what-if type calculations on an existing network. These calculations include newly proposed costs and resource levels, and enable networks to be refined toward optimality through an interactive mode using a multicolor graphics terminal, albeit with the manager providing the major impetus rather than a canned CDA or CRA optimizing routine. Stochastic SNAP is being used extensively at the Naval Air Development Center (NADC), William Grove, Pennsylvania where Computer Sciences Corporation acts as the management consultant assisting the Navy with Stochastic SNAP. In addition, two System Program Offices (SPO) at the Air Force Electronic Systems Division, Hanscom AFB, Massachusetts, are in the early stages of using Stochastic SNAP on remote terminals from NADC. Of the 10 or so network programs examined for this paper, Stochastic SNAP shows the most advantages and has the most promise as a contender for the next generation of network management programs. However, it is more complex than most, and hence may be more costly in the long run.

Cost Duration Analysis. When a project has been represented by a network management technique, further very useful information can be gathered by applying CDA. Each activity can be assigned a direct cost for completion at the estimated (normal) time. The total network direct cost is then the sum of all the activity direct costs, and the network

time is the sum of the times of the activities on the longest path through the network. It may be desirable to know something about the cost to complete the network in a shorter time, and costs for each activity at shorter times may be estimated. What is now necessary to know is which activities to shorten and by how much. The answer to that question is found through CDA. As mentioned previously, this analysis was an original part of CPM, and was extended to PERT. Many methods exist to solve this problem, and only some of the more prominent ones will be mentioned.

The primal-dual flow algorithm which Kelley originally used (Ref 17, 21) is still a valid method, but contained some assumptions which limited it somewhat:

(a) The true time-cost relationship of activities is continuous and convex.
(b) Linear or piecewise linear accurate approximations may be made to the true relationship for each activity.
(c) All activities are independent (Ref 19:27; 17:298).

Other methods which do not assume (a) or (b) above have also been developed. These include alternative solutions to linear (or piecewise linear) cost-time relationships, continuous convex curves, continuous concave curves, and a discontinuous nonincreasing function (Ref 12:61-118). This list is strictly representative, not exhaustive, and there are often more than one method to solve the problem for any given shape of the cost-time curve. Several comprehensive reviews of the state of the art of CPM and CRA have been published, Krishnamoorthy (Ref 23) in 1968, Dumas (Ref 10) in 1971, and Elmaghraby (Ref 12) in 1977. In general, these complex methods are intended to be computerized. They

often yield exact optimal solutions which, of course, are only as exact as the cost estimates made for the activities.

Of particular interest to managers should be methods which consider the resource availability along with cost-time trade-offs. One such "total package" approach to CDA and CRA was proposed by Burne (Ref 10). Another model which considers resource-duration interactions is presented by Elmaghraby (Ref 12:173).

In addition, there are some feasible heuristic methods which are considerably more simple, some of which can be done by hand (Ref 6:558; 9:104-107; 15:49-64; 17:104-132). These heuristic methods do not yield optimum solutions, but rather provide a high probability that a better than average solution will be identified. These heuristic methods often make assumptions which are valid only for specific uses of networking, and hence are limited in application. For simple applications, or in cases where valid simplifying assumptions can be made, these heuristics have the advantage of considerable cost and time savings.

Critical Resource Analysis. CRA is a type of analysis which may be used with a PERT/CPM network in which a resource is in some sense critical. A resource can be almost anything, but is most commonly specialized personnel or equipment. A critical resource is something whose use is in some way limited because of number, cost, availability, or other reason. CRA can take on two forms, depending on the project set up. If no set end date exists, but completion is desired as soon as possible, resource scheduling will be used to arrange activities in the network to fit the available resources. Various heuristic assignment rules exist which increase the chances of arriving at an optimal (minimum) project

duration. The other case is where a set end date exists for the project. Here, resources must be allocated within the available slack of the network, while observing the resource constraints present. This method is resource leveling, and is also solved by various heuristic assignment rules (Ref 6:567).

One marked difference between CRA and CDA is the lack of completely defined optimal methods in CRA. There are a few, but they are of limited application, and only rarely useful (Ref 12:169). The heuristic approach to a problem necessarily produces a proliferation of methods. Some of the most common are: allocate resources serially; schedule job with the longest (or shortest) duration first; schedule a particular department first; schedule job with least technical uncertainty first. Along with one or more of these, preference can be given jobs with the least slack, and non-critical jobs can, if possible, be rescheduled to free resources for critical jobs (Ref 6:566; 44:130). These are only a few of the possible rules, and many combinations of various rules are possible. Elmaghraby (Ref 12:155-168) and Dunne (Ref 10:21-24) list and discuss some of the more common heuristic methods.

Among the optimal methods available, the Branch and Bound (B&B) algorithm seems to be most prominent (Ref 2:ii; 12:204). However, the upper limit on the number of activities the B&B algorithm can handle has been claimed to be thirty (Ref 2:23). Integer Linear Programming models are also in use (Ref 12:169), as well as Assembly-line Balancing techniques (Ref 12:185).

Applications of Networking in the Literature

One impetus for this thesis was the apparent imbalance between theory and application in the literature. That initial observation was not unfounded, nor was it limited to any particular period of time. Certainly applications were not lacking, because some organizations were and still are using networking. What is lacking is documentation of these applications, and information about how widespread such applications are. There are notable exceptions, usually the "firsts" to use something, or comprehensive reviews done years later (Ref 14, 30, 31). This situation is particularly true for CDA and CRA. These two analytical methods, however, may also suffer from a true lack of applications, not merely a lack of documentation.

PERT/CPM Use in the Literature. As mentioned previously, PERT use was mandatory on major defense acquisition contracts for a period of about two years, and was still used after that, and continues to be used today in many areas of DOD acquisition. Present use will be discussed in Chapter III. Outside of DOD and its contractors, early PERT/CPM use was less standardized, but still substantial. A 1962 survey of major PERT users showed 66 percent of companies using it on military projects, 19 percent using it on commercial projects, and 15 percent using it on both (Ref 4:3). The number of users on which these percentages are based however, was not disclosed by the authors of the original report (Ref 8:156). In 1964 a survey of 183 PERT users showed about 40 percent using it on research and development, 35 percent were using it on construction, and various percentages less than 17 percent each in six other categories (Ref 14:18-19). A 1965 survey of 186 Fortune 500

Corporations showed results favoring construction, with only 48 percent using it for research and development, while 53 percent used it in construction (Ref 33). Other categories where PERT/CPM was being used in the above surveys were: Product Planning, Maintenance, Computer Installation, Marketing, Equipment Installation, First Run Products, and Systems and Procedures Installation.

During this time period, many companies reported excellent results using PERT/CPM, saving millions of dollars (Ref 7:20-22; 32:896). But at the same time PERT was coming under fire as being too rigid and inflexible to apply to all systems, and as having many pitfalls that unwary managers were falling into in increasing numbers (Ref 16:9). PERT/COST in particular began to be criticized widely, and its use eventually declined, in part due to the adoption of the criteria approach by the DOD, wherein standards for acceptable management systems were set, and PERT was no longer required for contractors (Ref 7:36; 14:53). Since that time, PERT/COST seems to have been used very little, while systems accomplishing essentially the same thing, but not called PERT/COST, have been in use.

CDA/CRA in the Literature. How much these two analytical techniques are used in industry today is not apparent from the literature. Nor is it apparent to what extent they have been used in the past. Some conclusions can be drawn from the surveys above. For instance, of the corporations using PERT/CPM in construction, a good many were probably using CDA and CRA. Construction has traditionally lent itself well to time-cost trade-offs for obvious reasons. Research and development, on the other hand, probably was not using the analytical methods to the

extent that the construction industry was. Aside from these generalizations, there are a few other conclusions that can be drawn from the literature.

Typical PERT/COST and early PERT publications used some applications in their text and report examples, but they were at a low level of sophistication, providing only a framework within which a manager could implement his own heuristic assignment rules (Ref 36:22-25). More sophisticated examples can be found in many textbooks, particularly more recent ones (Ref 6, 12, 17). These examples may be based on facts, but have been adapted for the teaching role. The same was found true for the outlines designed to be used to teach a PERT/CPM course (Ref 27). Occasionally, an article or paper may be found where the author uses concrete examples to illustrate his theoretical points (Ref 29).

For the most part then, information on CDA and CRA use remains based on speculation or inference. On the other hand, theory about CDA and CRA abounds. An informal survey of texts in the fields of Operation Research, Production Management and Industrial Engineering revealed that 23 of 29 texts examined contained a section on network management which included theory about CDA and/or CRA. The following chapters will report on an investigation of the use of PERT/CPM, CDA, and CRA in the aerospace industry, both government and private.

III Aerospace Applications of PERT/CPM

One of the research objectives of this paper is to determine to what extent PERT/CPM is being used today in the aerospace industry. This chapter presents the results of 114 contacts made with potential PERT/CPM users in the military and private industry. A summary of the results of these interviews is presented in Tables I through XIV. In surveys done by others (which were discussed earlier in this paper) many industries were examined to determine their use of PERT/CPM. This paper concentrates on one particular industry to determine the pattern of use of PERT/CPM and CDA/CRA. In addition to use or non-use of PERT/CPM, this chapter also contains information on: type of method used; the extent to which PERT/CPM is used in each organization; type of project used on; experience and training of individuals interviewed; availability and use of computers; and the opinions of those interviewed about the usefulness of PERT/CPM.

Analysis of Air Force Utilization

There are some basic functional and organizational differences between the Air Force and industry which prevent a joint discussion of some areas of PERT/CPM use. For this reason, PERT/CPM usage rate, type of method used, and frequency or mode of operation will be treated separately. The remaining topics of experience and training, availability and use of computers, and user assessment of PERT/CPM usefulness will be treated jointly.

Forty-eight Air Force organizations were contacted, and PERT/CPM use information was obtained from all of them. Air Force organizations, unlike industry, can be aggregated into large functional areas. The distribution of contacts made in this study was as follows:

Air Force Systems Command (AFSC)

Aeronautical Systems Division (ASD)	20
AF Wright Aeronautical Laboratories	5
AF Human Resources Laboratory	1
6570th Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio	1
Space and Missile Systems Organization (SAMSO), Los Angeles AFS, California	10
Electronic Systems Division (ESD), Hanscom AFB, Massachusetts	9

Air Force Logistics Command (AFLC)

Air Force Acquisition Logistics Division (AFALD), Wright-Patterson AFB, Ohio	1

Air Force Audit Agency (AFAA)

ASD Audit Office, Wright-Patterson AFB, Ohio	1

For a complete list of organizations contacted, consult Appendix A. These organizations are not meant to be an exhaustive list of PERT/CPM users, but rather a representative sample. Because of its proximity to the Air Force Institute of Technology, ASD was given more thorough treatment than other organizations, but the usage pattern and percentage are believed to be consistent in similar organizations regardless of geographical location.

While contacting individuals in an organization, every effort was made to obtain a complete interview from those who were currently using PERT/CPM. The structured interview format in Appendix C was used for

this purpose. In only five of 18 organizations currently using PERT/CPM was this not possible. In addition, five individuals who had used PERT/CPM in the past were interviewed, as well as three who reported the definite intention to use it in the future, and one person who found PERT/CPM completely unsuitable in his area of responsibility. This made total of 22 individuals interviewed who were employed by the Air Force in aerospace acquisition management. Appendix B is a listing of individuals interviewed, categorized by Air Force, industry, and PERT/CPM vendors.

PERT/CPM Usage. Of the 48 Air Force organizations contacted, 18 were currently using some form of PERT/CPM for management. Five organizations reported having used PERT/CPM in the past, but they were not using it currently. There were 25 organizations not using any form of PERT/CPM. Table I shows these figures, and the fact that 38 percent of the organizations contacted in the Air Force are currently using PERT/CPM.

The extent to which the 18 using organizations utilized PERT/CPM varied considerably. About half had a rather large and complete network management system implemented. The remainder used PERT to a markedly lesser extent. The large network systems are characterized by a standard reporting system extending throughout the organization, and at least one staff member dedicated solely to the creation/update of activities in the network. A management consultant firm is often utilized under contract to the organization as the operator of the system, and the consultant firm usually owns the software being used to maintain the network on the computer. These owners/operators of PERT/CPM system

Table I

PERT/CPM Usage

	Military*	Industry	PERT/CPM Vendor	Total
Organizations Contacted	48	60	6	114
Information Received	48	51	6	105
Currently using PERT/CPM	18	24	6	48
Past user of PERT/CPM	5	4	-	9
Not now using PERT/CPM	25	23	-	48
Interviews Conducted	23	28	6	57
Currently using PERT/CPM	14	24	6	44
Past user of PERT/CPM	5	4	-	9
Never used PERT/CPM	4	0	-	4
Percentages of Information Received				
Currently using PERT/CPM	38%	47%	100%	46%
Past user of PERT/CPM	10%	8%	-	9%
Not now using PERT/CPM	52%	45%	-	46%

*includes one U. S. Army Corps of Engineers construction project.

software are what have been called PERT/CPM Vendors in this paper. These Vendors and their systems will be described further in a following section.

The other half of PERT/CPM users in the Air Force sample are small, often one man operations. These networks are usually on the order of at most 300 activities. Two were maintained manually, while the remainder were computerized. Typically, the manager using a small PERT/CPM network has had some prior experience, either practical or academic, with networking. The computer program used with these smaller networks is generally simpler than is the case with the larger systems, and in no case contained any provisions for CDA or CRA.

Type of Method Used. The actual method used by each respondent was determined, and is presented in Table II. PERT was the most common response, followed by CPM. These distinctions were drawn by the users, not the interviewer. No specific attempt was made to determine whether one or three time estimates were used, nor whether Activity-on-Arrow or Activity-on-Node networks were in use. In the course of some interviews, it became apparent that some respondents were using one time estimate, yet calling the technique PERT. In this research, the position is taken that the distinctions between PERT and CPM have become blurred over the years, and the empirical evidence seems to support that position. The other methods listed in Table II are specific computer programs used by some of the organizations interviewed. These programs are believed to be representative of the various other PERT/CPM programs available. SNAP has already been described in Chapter II of this paper. PMS IV will be discussed under the industry analysis section in this chapter.

Mark III, Concord II, and Oscar will be discussed in the section of this chapter dealing with PERT/CPM Vendors.

Table II

Type of Method Used

	Air Force	Industry	Vendor
PERT	9	17	
CPM	1	7	
PERT & CPM	1	3	
PMS IV (IBM)		1	
Mark III (Program Control Corp)	5		3
Concord II (Concord Industries Inc.)	1		1
SNAP (Computer Sciences Corp.)	2		1
EZPERT (Systonetics Inc.)	3		
OSCAR (On-Line Systems Inc.)			1
Total	22	28	6

EZPERT (pronounced "Easy PERT") is strictly speaking not a PERT program, but a collection of plotting routines designed to be used in conjunction with a standard computer PERT package. The package used at Wright-Patterson AFB is the CDC PERT-TIME program. Output from this program can be channeled to EZPERT, which produces the desired network plot on a computer driven plotter such as a CALCOMP plotter. There is a distinct improvement in the readability of a graphic display of a

network, as compared to a computer line printer output. Other such PERT plotting routines exist, and one of these, called NETPLOT, is also in use at Wright-Patterson AFB and elsewhere in the Air Force.

Air Force-Contractor Interface. There are several different ways in which Air Force PERT/CPM networks can be created and maintained. The networks can be solely Air Force created and maintained where the information is derived from required contractor reports. Original networks may be created by a contractor, then the Air Force can maintain them. A contractor may create and maintain a network, providing information copies to the Air Force. The first option, an Air Force created and maintained network, is being used by 10 of 13 Air Force organizations currently using PERT/CPM. One organization monitors contractor created and maintained networks, and the remaining two organizations maintain contractor created networks. In the context above, contractor means the major or prime contractor for the program, as opposed to a management consultant type contract in which the PERT network may be created and maintained for the Air Force under contract with a PERT/CPM Vendor.

There is another type of operation which was not found to be used in the sample of organizations in this study, the joint Air Force-Contractor network. These types of networks were in use previously, but were apparently abandoned as a viable method. In a joint network, either party may create or modify activities or whole networks. In one organization which had previously used joint networks, the problem was summed up as one of documentation. One party would make changes without the other's knowledge, causing considerable problems (Ref 37:108). Apparently close cooperation between the Air Force and a contractor has

its limits, since now almost all Air Force networks are created and maintained solely by the Air Force.

Analysis of Industry Utilization

Sixty organizations were contacted in private industry, and responses were obtained from 51. The nine non-responding organizations were so for various reasons, most commonly this investigator's inability to circumvent various bureaucratic snarls. Some organizations were quite secretive about their management practices, and others practiced a circular version of pass the buck.

In the case of five corporations, it was necessary to contact more than one division to get complete information. This occurred in companies with decentralized control functions in which no person at the corporate level was knowledgeable enough about the PERT/CPM use of the various aerospace divisions in the company. Appendix A lists organizations contacted, with notation of their PERT/CPM and CDA/CRA use or non-use.

In the 51 organizations from which information was obtained 28 interviews were conducted. Current users were 24 of these 28, while the remaining four were past users of PERT/CPM. Appendix B contains a listing of individuals interviewed.

PERT/CPM Usage. Table I shows the breakdown of PERT/CPM users in industry, and how they compare to military organizations. The 47 percent use of PERT/CPM in industry appears to be somewhat larger than the 38 percent use of PERT/CPM by the military. This is believed to be a true reflection of reality, and in fact may be more pronounced when

only larger private industry organizations are considered. In order to obtain the broad spectrum of opinion and sample various types of organizations, some smaller, local firms were included in the sampled organizations. These smaller firms were typically employing less than 50 people, and were locally owned and operated. Six such firms were contacted, and only one is using PERT/CPM. When these six organizations are excluded, the PERT/CPM use percentage increases to 51 percent. This percentage is believed to be a more reasonable figure to compare to military organizations, since the sizes of the organizations being compared are better matched. An analysis of PERT/CPM users by size was rejected because of the difficulty of suitable criteria for grouping.

Type of Method Used. Table II lists the industry responses concerning methods being used. The comments made about the military responses are also true of the industry responses, that is, they are user perceptions of what his organization is using as a technique. Some small manual networks were being used by individuals in some companies, but these three users were a minority. The majority of the using organizations used automated techniques, but the extent of application varied from simple time-only CPM networks to large complex systems with costs and resources included.

Grumman Aerospace Corporation uses a management system designed by IBM called the Program Management System IV (PMS IV). This package consists of four modules or processors: Network Processor; Report Processor; Resource Allocation Processor; Cost Processor. Together these processors make a complete network management system, including all aspects of PERT/COST. The Cost processor has provisions for establishing

time-cost relationships for various functional activities based on step, linear or non-linear functions. Unfortunately, no provision is made for Cost Duration Analysis (Ref 18:20-21). The Resource Allocation Processor does perform Critical Resource Analysis functions, including both resource leveling and resource scheduling. The technique used by this processor is the serial-parallel allocation procedure, in which activities are started as soon as possible when resource constraints allow. If restrictions exist on resources which prevent activities from starting as soon as possible, then selected priority rules are applied. Up to three of these rules may be used in combination, and the user may select from a list of seven of these heuristic allocation rules (Ref 18:26-31).

Although lacking CDA, PMS IV still remains an excellent Management system. No specific data was obtained on the costs to use PMS IV, but the complexity of a full system of all four processors leads one to believe it might be substantial. Quite a few other network management systems are available, with varying degrees of complexity and hence cost. A summary of these programs was published in July 1976, including several others with CDA and/or CRA (Ref 22:11).

How Often PERT/CPM Applied. Each private industry user of PERT/CPM was asked how often this technique was used in his organization. The responses to this question are summarized in Table III. The most interesting figure in this table is the almost 30 percent who reported being required to use networking on some government contracts, or by some commercial customers. PERT has not been required on all Defense Acquisition contracts for over 10 years, but apparently it is being

required by a substantial number of managers in the position to dictate its use. This was confirmed by two Air Force organizations, one quite large and one smaller, which require the use of networking on all contracts.

Table III

How Often PERT/CPM Applied

How often PERT/CPM is applied by private industry firms reporting the use of PERT/CPM		
Every Project	3	13%
Normally	10	42%
Occasionally or on exception basis	4	17%
When required to by contract/customer	7	29%
Total	24	100%

Of the three organizations who reported use on every project, only one (Grumman) uses a large, complete networking system. Another is a large aerospace accessory manufacturer in which CPM is used by all project managers. The last is a small local aerospace operation which makes extensive use of CPM.

The organizations reporting normal use of PERT/CPM indicated use on "most" or "almost all" projects. Generally use was up to the project manager, but often central planning and control groups were available to assist him, particularly with computer applications of networking.

The occasional users mentioned using PERT/CPM on a few projects, generally only their largest ones. These users expressed no knowledge of any requirements to use PERT/CPM on any projects. This is as opposed to the users required to apply PERT/CPM by contract/customer, who were obviously also occasional users of PERT/CPM, but were using it, at least in some cases, only because they were being forced to do so.

Type of Project Used On

In Chapter II, surveys were reviewed which indicated PERT/CPM use on many types of projects, but Research and Development (R&D) and construction were the major areas. While limited in this paper to aerospace industries, two construction uses of PERT/CPM will be mentioned for purposes of comparison. First, however, the aerospace uses shown in Table IV will be outlined briefly.

Table IV

Type of Project PERT/CPM Used On

	Air Force	Industry	Total
Research and Development	20	26	46
Production	0	1	1
Auditing	1	0	1
Construction	1	0	1
Not Specified	0	1	1

Aerospace Areas. Not surprisingly, the vast majority of aerospace applications were in the area of R&D. Inherent in today's aerospace industry is a need for large amounts of R&D, and PERT had its beginnings in this area as well. Table IV shows that of 50 organizations interviewed in the aerospace area, 46 were using PERT/CPM in the R&D field. Only one firm reported use in production, and this was a small local operation. This firm acknowledged that the use of CPM in production was not ideal, but the cost of a separate production oriented system such as Line-of-Balance would be prohibitive.

An interesting application of PERT was found in the auditing field. Planning audits can be quite a complex task, and the interrelationships of schedule and personnel problems can be represented by a PERT network quite well. An article documenting some auditing applications of PERT has been published (Ref 24), and the individual who was interviewed for this paper is planning to implement a PERT network in his area of responsibility.

A word of explanation is necessary about the construction use of PERT/CPM included in the aerospace area uses of PERT/CPM. This application is for the design, building, and installation of equipment in the Compressor Research Facility at Wright-Patterson AFB. The management of this effort is under the control of an aerospace organization, the Aeronautical Propulsion Laboratory. The personnel involved have had extensive experience in aerospace management, and the techniques being used are more closely related to those being used elsewhere in the aerospace area (Ref 37:14). For these reasons, this construction application of PERT/CPM has been included in the aerospace area. It is in

reality an aerospace organization managing the acquisition and installation of equipment for a new and complex research facility, and cannot fairly be compared with the construction of, say, an office building.

Construction Area. In addition to the aerospace related construction above, one other construction PERT/CPM user was interviewed. The construction project in question is in Lima, Ohio and involves over 40 million dollars administered by the U. S. Army Corps of Engineers. The Corps is integrating contractor for the building of a new plant for the construction of the Army's new battle tank. CPM is used extensively by the Corps on this project, and is a contractual requirement for all participating private industry. No CDA or CRA is in use now, although prior use of CRA on a different project was mentioned. The interesting thing about this application of CPM is that it differs in no appreciable way from many in the aerospace industry. Construction and R&D applications have in the past been thought of as different types of network management, but the evidence, albeit based on only two construction projects, indicated that there may now be little if any difference. This tendency has also been accentuated by the use of well integrated network management systems (such as IBM's PMS IV) by the aerospace industry. The impetus behind such a tendency is thought to be the transition away from the time critical management period of the 1960's to the more resource critical management period of the 1970's. It appears that aerospace may have gained from the construction industry in the knowledge of effective means of resource planning and control.

Experience and Training

Six questions asked in each interview dealt with the experience of the organization or individuals' training in PERT/CPM. The results are presented in Table V, categorized by Air Force and Industry.

Experience. There is a gap of over six years between the personal experience of Air Force and industry users. This gap is believed to be the result of personnel turnover in the Air Force, and generally reflects the younger work force in the Air Force in comparable positions of responsibility. The gap between organizational experience in the Air Force and industry is more than likely a reflection of the personal experience gap. This could come about because of the self-reported nature of this information, since the less experienced Air Force personnel would be likely to have less than completely accurate ideas of how long their organizations had, in fact, been using PERT/CPM.

Training. The type of training received also reflects the younger Air Force managers, with the larger number of Air Force users having had college courses with PERT/CPM than had the industry managers. Industry users seem to have had more formal organizational training and on the job training than Air Force users. However, checking the correlation between formal organization training and whether the course is still offered, only two of the industrial users who have had the training say that the courses are still being offered. Another noticeable difference is the hours of formal training received. The average number of hours for current users in industry is much higher than for the Air Force. These differences point out that when industry did provide PERT/CPM training, it provided more than the Air Force, and that the Air Force

Table V

Experience and Training of Current PERT/CPM Users

	Air Force (n=13)	Industry (n=24)
Average organization's experience in years, with range in parentheses	9.7(1-18)	13.4(2-19)
Average personal experience in years, with range in parentheses	5.2(1-15)	11.4(2-18)
Type of training received (number of times mentioned)		
Undergraduate	4	0
Postgraduate	6	4
Formal organizational	1	9
On the job training (OJT)	8	23
Average amount of training received in hours, with range in parentheses (OJT not included)	9.6(6-30)	16.6(6-30)
Average years since last training, with range in parentheses (OJT not included)	5.1(1-13)	10.8(3-16)
Course taken (or similar course) still offered?		
yes	9	5
no	0	8
uncertain	1	0
not applicable (OJT only)	3	11

has now come to rely more heavily on academic training, rather than formal organizational training.

Availability and Use of Computers

While the use of a computer is not a necessity for any PERT/CPM network, networks of any size can quickly become quite cumbersome to do manually. Three separate questions about computer use were asked during each interview to obtain the full information. Questions were asked to determine computer availability, PERT/CPM program availability, and whether the program was being used. Table VI presents the responses to these questions for current PERT/CPM users. All Air Force users had both computer support and a PERT/CPM program available, although one individual was uncertain of this. Only three Air Force current users of PERT/CPM were not using computer support. Of current industrial PERT/CPM users, two had no computer support available. Five industrial users had a computer available but no PERT/CPM program, and one was uncertain. Three additional industrial users were not making use of an available program, for a total of eleven industrial PERT/CPM users who were using a manual system. There are 46 percent of industrial users who manually create and update networks, while only 23 percent of Air Force managers using PERT/CPM do this. Perhaps the difference can be explained by the availability of Air Force computing support, since an Air Force manager has to worry little, if any, about the cost of such computer support to his project.

Table VI

Computer Availability and Utilization
by Current PERT/CPM Users

	Air Force	Industry
Computer support availability		
Yes	13	22
No	0	2
PERT/CPM program availability		
Yes	12	16
No	0	3
Uncertain	1	1
Computer unavailable	0	2
Current use of PERT/CPM program		
Yes	10	13
No	3	3
Program unavailable	0	8

Vendors of PERT/CPM Techniques

At many major military aerospace acquisition organizations, the actual day to day operation of network management systems is being done by private organizations under contract to the government. These contractors are known by many names, but "management consultants" is a frequently used generic term for them. They have been called PERT/CPM vendors in this paper to differentiate them from other types of management consultants, but also to make it clear that most of them are also

selling the government a product, generally a software package. Representatives from four such organizations were interviewed, totaling six interviews in all. All four systems have features which make them better than any other, according to the individuals interviewed. This has some truth in it, since each has some redeeming features, and there is no one system which stands out among the rest. Three make claim to being interactive, to varying degrees. All have the capability to track costs and other resources, but none has the ability to optimize as in the classical type of CDA or CRA. The display of networks varies somewhat, but SNAP (described in detail in Chapter II) has the ability to display networks on a graphics equipped Cathode Ray Tube (CRT). This is a distinct advantage, giving a manager quick and easily visible feedback on changes. This feature can lead to easily implemented heuristic type CDA or CRA. Two other systems can use CRT's for input or output, but not for graphic displays of a network. Non-CRT displays of networks include a bar chart format which also indicates all interrelationships, and a classical computer produced network diagram. Specific information on any of these methods can best be obtained from the vendors themselves, listed in Appendix A.

Because of the obvious bias which these vendors have toward PERT/CPM systems, they have been excluded from consideration in much of the foregoing analysis, and will be explicitly identified and corrected for in the following analysis of results.

User Assessments of PERT/CPM

Each person interviewed was asked two questions about his opinion of the usefulness of PERT/CPM. The first question asked about

usefulness for planning a project, and the second asked about usefulness for controlling and scheduling a project. Both questions were answered using the same numerical scale of one to nine, ranging from the worst seen or used to the best seen or used. The text of the questions and the complete scale used (Scale B) are found in Appendix C.

Planning Usefulness. The results of this question are shown in Table VII. The table is a copy of the output from SPSS, modified only slightly. The column labeled "code" is the value on the one to nine scale, and the absolute frequency column gives the number of responses for each code. There were four individuals who declined to rate PERT/CPM, indicated by the "no response" category label. These individuals felt that they had not had enough experience to fairly rate the technique. There were six PERT/CPM vendors interviewed, and all six rated PERT/CPM as nine for planning, and also for controlling. Since these individuals are selling PERT/CPM as a business, they are certainly biased. The relative frequency column includes the non-responses and Vendors, while the adjusted frequency column does not. The statistics following the table have been calculated without the non-responses and vendors.

By far the most common response is that PERT/CPM is the best thing available for planning, with 70.2 percent of the individuals rating PERT/CPM giving it the highest possible rating. The mean of the responses was 8.255, and a 95 percent confidence interval about this mean ranges from 7.812 to 8.699.

Controlling Usefulness. Table VIII shows the results of this user assessment of PERT/CPM controlling usefulness. The arrangement, scales

Table VII

PERT/CPM Planning Usefulness

Category Label	Code	Absolute Freq	Relative Freq (Pct)	Adjusted Freq (Pct)	Cum Freq (Pct)
Worst Used or Seen	1	0	0	0	0
A Little Better than Worst	2	0	0	0	0
Better than Worst	3	2	3.5	4.3	4.3
Not Quite as Good as Others	4	0	0	0	4.3
Same as Others	5	2	3.5	4.3	8.5
A Little Better than Others	6	1	1.8	2.1	10.6
Better than Others	7	3	5.3	5.4	17.0
Not Quite the Best	8	6	10.5	12.8	29.8
Best Used or Seen	9	33	57.9	70.2	100.0
Deleted (No Response or Vendor)	Blank	10	17.5	Deleted	
	Total	57	100.0	100.0	

Mean 8.255
Standard Deviation 1.510
95% Confidence Interval 7.812 to 8.699

Table VIII

PERT/CPM Controlling Usefulness

Category Label	Code	Absolute Freq	Relative Freq (Pct)	Adjusted Freq (Pct)	Cum Freq (Pct)
Worst Used or Seen	1	0	0	0	0
Not Quite Worst	2	2	3.5	4.3	4.3
Better than Worst	3	6	10.5	13.0	17.4
Less than Others	4	3	5.3	6.5	23.9
Same as Others	5	5	8.8	10.9	34.8
A Little Better than Others	6	4	7.0	8.7	43.5
Better than Others	7	12	21.1	26.1	69.6
Not Quite the Best	8	1	1.8	2.2	71.7
Best Used or Seen	9	13	22.8	28.3	100.0
Deleted (No Response or Vendor)	Blank	11	19.3	Deleted	
	Total	57	100.0	100.0	

Mean 6.348
Standard Deviation 2.263
95% Confidence Interval 5.676 to 7.020

and statistics are identical with those of Table VII described above. The responses to this question fall generally lower than for planning usefulness, but 28.3 percent of the respondents think PERT/CPM is the best method available for controlling. The mean of 6.348 puts the average response somewhat above "a little better than the others." The 95 percent confidence interval about this mean ranges from 5.676 to 7.020, a larger range than for planning usefulness, which along with the larger standard deviation of the controlling usefulness indicates a greater diversity of opinion about controlling than planning usefulness of PERT/CPM.

Summary of Aerospace Applications of PERT/CPM

Information was received about PERT/CPM use from 105 organizations out of 114 contacted. Of these 105, 48 were currently using PERT/CPM, or 46 percent of those from whom information was obtained. In addition, at least nine organizations were past users of PERT/CPM, and all nine of these were interviewed. In all, 57 interviews were conducted in person and by telephone, 23 with military organizations, 34 with private industry users or vendors of PERT/CPM. Table I shows the complete breakdown of results of these contacts.

Research and Development was the most common type of project PERT/CPM was used on in both the Air Force and industry, with 92 percent of the users in this paper being in that situation. The experience and training of the organizations' personnel shows some significant differences between Air Force and industry, both in experience and training. The Air Force apparently has individuals with more recent academic

training, while industry has much more experience and on the job training. Six organizations have computer programs available but are not using them, and eight organizations have no PERT/CPM computer program available to them. The remaining 23 current PERT/CPM users are using computers, for 62 percent computer use with PERT/CPM.

The final section in this chapter presented the results of the opinion of all individuals interviewed about the usefulness of PERT/CPM for planning, and its usefulness for controlling and scheduling. On a scale of one to nine, the mean for planning usefulness was 8.26, and the mean for controlling usefulness was 6.35. These results show that managers perceive PERT/CPM as being significantly more useful for planning than for controlling.

Along with the investigation of the use and opinions about PERT/CPM, knowledge of the use of CDA and CRA by aerospace managers could be useful. Questions about the use of CDA and CRA were asked on all interviews, and the results are presented in Chapter IV.

IV Aerospace Applications of CDA and CRA

Cost Duration Analysis

Since CPM was first developed by Kelley in the late 1950's, CDA has been associated with network management techniques. CPM, because of its deterministic nature, was associated more closely with the construction industry than any other industry for many years. Also, despite the basic differences in structure between PERT and PERT/COST, CDA has become associated in some manager's minds with PERT/COST. These factors and other influences have caused considerable differences of opinion among managers in the aerospace field about the usefulness of cost analyses of any kind associated with network management systems.

Two steps are necessary to implement CDA in a network. First, cost-time relationships must be established for each activity; secondly, these relationships and other outside factors must be analyzed in some manner to obtain an optimum or near optimum time-cost trade-off. The first of these steps has been accomplished in a simplified manner by a number of PERT/CPM users. This allows the network to be used as a means of cost tracking and control during project execution, as opposed to the normal pre-execution use of CDA. This process will be referred to as cost tracking, and can be thought of as a technique related to, but not as complex as CDA.

Cost Tracking

Cost tracking uses some of the same concepts as PERT/COST, but is not nearly as complex as PERT/COST. In cost tracking, a cost estimate

is made for each activity in the network resulting in an overall project planned or budgeted cost versus time curve. Each of the cost tracking programs has the capability of showing budgeted versus actual amounts spent to date, either graphically or in tabular form. The graphic form is often two cost versus time curves plotted on the same graph, which can be generated for the whole project, or any sub-part thereof. The source of information for the actual cost curve varies between Air Force and industry systems, however. The Air Force assumes a certain percent of funds expended based on the elapsed time since an activity has started, while industry practice is to use actual figures as accumulated in accounting systems. Of course, industry users of cost tracking also have need for and regularly use projected figures.

The use of cost tracking by current PERT/CPM users is presented in Table IX. There are one Air Force and two industry organizations now using cost tracking, for eight percent use. Three PERT/CPM vendors are also using cost tracking, and when these three are included, the total current use rate is 14 percent. In addition, two organizations in industry had used cost tracking, but no longer do. While cost tracking is not being used extensively, its use does show that some managers are using PERT/CPM networks with costs, but short of the complexity of CDA.

Time-Cost Optimization. The optimization of cost versus time is really the central issue in CDA. This optimization was done by only two industry users of PERT/CPM, and three organizations have used it in the past. There were no organizations in the Air Force sample that used CDA. Two PERT/CPM vendors were using CDA, but not at any organizations interviewed for this paper. Thus, of 43 organizations using

Table IX

CDA Usage by Current PERT/CPM Users

	Air Force	Industry	Vendors
Never heard of it before	1	0	1
Heard of it in passing	7	4	0
Need more information about 't to decide if suitable	2	0	0
Not suitable for use in my organization	1	11	0
Will probably use in the future-CDA	1	1	0
Have used it in the past			
Cost Tracking	0	2	0
CDA	0	3	0
Now using			
Cost Tracking	1	2	3
CDA	0	2	2
Total	13	24	6

PERT/CPM, less than five percent are using CDA if vendors are excluded, and about nine percent if the vendors are included. This includes some quite large organizations with large network management systems. The availability of computer programs for CDA could be a factor in this, but the following data seems to indicate otherwise.

CDA Computer Program Availability. Table X is a summary of the availability and use of CDA computer programs. In answer to whether sufficient CDA programs are available, notice that two Air Force organizations have CDA programs available, but are not using them. If

industry had the need for these programs, it could have the use of the programs, since the two are commercially available. It is reassuring to note that there are no industrial organizations which have CDA programs available and are not using them. One final fact is that five industrial PERT/CPM using organizations have had CDA programs available in the past, but no longer do. Additional comments received in interviews revealed that two industry and one Air Force organizations which no longer use PERT/CPM report having had a CDA program available and also having used CDA. Those facts all seem to suggest that CDA may have some serious drawbacks.

Table X

CDA Computer Program Availability
by Current PERT/CPM Users

	Air Force	Industry	Vendors
Program available, using			
Cost Tracking	1	2	3
CDA	0	1	2
Program available, not using			
Cost Tracking	3	0	1
CDA	2	0	0
Program not available	7	13	0
Computer not available	0	2	0
Used to be available	0	5	0
Uncertain	0	1	0
Total	13	24	6

Evaluation of CDA by Users. During each interview, questions were asked about why the individual was using or not using CDA. Both positive and negative reasons were recorded. These reasons or factors for use or non-use of CDA form an evaluation of the technique, since they represent both sides of the question. Current users, past users, and those who had never used CDA were tabulated separately, using the computer technique called CROSSTABS, which is a part of SPSS.

All responses are shown in Table XI, the numbers in the table being the number of times the particular response was recorded. Each individual was allowed three positive and three negative factors. No attempt was made to fill these numbers of responses, nor were any factors suggested during interviews. The factors tabled are ones that the individuals being interviewed offered, with only very minor combinations for space and readability. The positive factors of "Got government contracts" and "Eyewash" need a word of explanation. The individuals making those comments perceived CDA as benefitting them because of its ability to convince prospective customers that they had a sophisticated management system.

For current CDA users, there were 16 positive responses to 14 negative, coming from nine interviews. However, five of these nine interviews were with PERT/CPM vendors using CDA, and their objectivity is doubtful. The most vociferous negative responses came from those who had never used CDA. In the 28 interviews of the individuals who had never used CDA, only four expressed any further interest in CDA by saying they might use it in the future or needed more information about

Table XI

CDA Evaluation by All with PERT/CPM Experience

Number of Times Response Recorded				
	CDA Use			Total
	Current	Past	Never	
Positive factors				
Fast	5	5	5	15
Accurate	5	2	6	13
Handles large amounts of data	4	1	4	9
Eyewash	2	1	2	5
Got government contracts		2		2
Negative factors				
Too complex	3	3	17	23
Too expensive	3	3	13	19
Not necessary	2	4	11	17
Lack of acceptance	4		6	10
Slow update		2	2	4
Needs too much data		1	2	3
Inaccurate data used			2	2
Overlaps CSCSC	1		1	2
Makes managers decisions	1		1	2
Forced to use it		1		1
Scatters responsibility			1	1
Inflexible			1	1
Meaningless			1	1
Number of Interviews	9	8	34	51

it. Past users of CDA leaned toward the negative, with 14 negative and 11 positive factors recorded on eight interviews.

In summary, the most often mentioned reasons for not using CDA were its complexity and cost. Those who had positive comments most often said CDA was fast and accurate.

Critical Resource Analysis

CRA has also been associated with CPM for many years, and like CDA is believed to suffer from false association in some manager's minds with PERT/COST. Like CDA, CRA may be viewed as a two step process. In CRA, the resource requirements of each activity must be known, as well as the overall resource constraints of the project. These resource constraints have most often been manpower limitations, and only one other resource was found used with CRA in the investigations for this paper. The second step in CRA is the allocation of the limited resources to the network following some heuristic allocation rules. A number of the organizations contacted did accomplish the first step toward CRA of establishing the manpower-time relationships for the network in use, and this has been called manpower loading. This manpower loading as used here refers specifically to this operation only as done in direct association with a PERT/CPM network, and not the manpower loading associated with non-network manpower management. Table XII presents the results of CRA use by current PERT/CPM users.

Manpower Loading. Only one Air Force organization is now using manpower loading, while two industry organizations are now using it and two have used it in the past. Three PERT/CPM Vendors are also using manpower loading, and each uses quite similar computer methods to display them. Outputs from these manpower loading computer programs usually take the form of a histogram of manpower use versus elapsed time since the beginning of the project. Most users of manpower loading were of the opinion that no further automated analysis was needed. They thought that the managers should be in the decision making process about

Table XII

CRA Usage by Current PERT/CPM Users

	Air Force	Industry	Vendors
Never heard of it before	1	0	
Heard of it in passing	7	3	1
Need more information about it to decide if suitable	3	0	
Not suitable for use in my organization	1	13	
Will probably use it in the future	0		
Have used it in the past:			
Manpower Loading	0	2	0
CRA	0	3	0
Now using:			
Manpower Loading	1	2	3
CRA	0	1	2
Totals	13	24	6

resource allocation, and resisted any suggestion that a set method, computerized or not, should take that prerogative away from the manager. Further evaluations of why these users of manpower loading are not interested in using CRA are found in the section on evaluation of CRA.

Resource Allocation. Once the manpower loading histogram has been established, CRA may be accomplished on the network to level the histogram to meet a restriction on manpower levels. This may or may not be

possible within the original project duration. If it is not, resource scheduling allocation rules can be applied to keep the project duration to a minimum, while still obeying manning restrictions. There were no Air Force organizations using CRA, and only one industry user currently using CRA. Two PERT/CPM Vendors are using CRA at present, but not at an organization interviewed for this paper. In addition, three industry users of PERT/CPM reported having used CRA in the past. From verbal descriptions of other CRA computer techniques, they seem to follow the same format as the PMS IV resource allocation processor described in the industry section in the previous chapter. Since CRA was used by three organizations in the past, they apparently had computer programs at one time.

CRA Computer Program Availability. Table XIII contains the results of the availability of computer programs for CRA and manpower loading. Notice, as in CDA, that the Air Force has CRA and manpower loading computer programs available but is not using them. Apparently industry finds this economically unwise. Also as with CDA, if industry needed or wanted CRA programs, they could get them, since there are at least four available commercially.

While computer programs certainly are justified on larger CRA problems, some smaller problems can be handled with a manual CRA technique. A past PERT/CPM and CRA user reported good success with such a manual CRA in scheduling the dispatch of fuel trucks on a large government flying installation. Priority rules formed the basis of the simple heuristic assignment algorithm used, and results were much improved over previous schemes.

Table XIII

CRA Computer Program Availability
by Current PERT/CPM Users

	Air Force	Industry	Vendors
Program available, using			
Manpower Loading	1	1	3
CRA	0	1	2
Program available, not using			
Manpower Loading	3	0	1
CRA	1	0	0
Program not available	7	14	0
Computer not available	0	2	0
Used to be available	0	4	0
Uncertain	1	2	0
Totals	13	24	6

Evaluation of CRA by Users. The same questions asked of each individual interviewed about CDA were asked about CRA. There were no evaluations of CRA by anyone who had not used PERT/CPM before. The evaluations are presented in Table XIV in the same format as the CDA evaluations previously presented. Two additional negative factors were added to the list for CRA. "Personnel objections" referred to the feelings of the people being allocated. This category included organizations which reported that their unions would not allow any sort of manpower control by computerized methods. "Always undermanned" is the common complaint of many people, but here they meant that being

Table XIV

CRA Evaluation by All with PERT/CPM Experience

Number of Times Responses Recorded				
	CRA Use			
	Current	Past	Never	Total
Positive factors				
Accurate	4	4	5	13
Fast	5	2	3	10
Handles large amounts of data	5	2	3	10
Eyewash	2	3	1	6
Got government contracts		2		2
Negative factors				
Too complex	2	3	21	26
Too expensive	2	4	11	17
Not necessary		4	12	16
Lack of acceptance	4		6	10
Slow update		2	2	4
Inaccurate data used			3	3
Makes managers decisions	2		1	3
Needs too much data			2	2
Overlaps CSCSC	1		1	2
Personnel objections		1	1	2
Always undermanned			2	2
Forced to use it		1		1
Scatters responsibility			1	1
Inflexible			1	1
Meaningless			1	1
Number of Interviews	9	8	36	51

undermanned would not allow CPA to be used because people could not be moved from one project to another. As before, these evaluations are self-reported by the persons interviewed, and are their perceptions of why they are using or not using CRA. Not surprisingly the current users of CRA list more positive factors than negative, while the opposite is true for others. Notice that the largest number of mentions of negative factors was "too complex" and "too expensive," the same top two as for the CDA evaluation. Also as with CDA, most of the opposition to CRA comes from those who have never used it, and 14 of the 29 who fit this label express no desire to know any more about CRA.

Summary of Aerospace Applications of CDA and CRA

The use of CDA and CRA by those currently using PERT/CPM was investigated, and the results are shown in Tables IX and XII, respectively. There were four organizations using CDA, or 9.3 percent. There were three organizations using CRA, or 7 percent. Considering CDA and CRA together, there were six organizations, or 14 percent, who were using a type of analysis on PERT/CPM networks which amounted to a step toward CDA or CRA, called cost tracking and manpower loading, respectively.

Three Air Force organizations had CDA or CRA computer programs available, but were not using them. Six more had cost tracking or manpower loading programs available, but were not using them. This situation was not found in industry, since such unnecessary costs are apparently controlled more closely in industry.

Comments by those currently using CDA and/or CRA indicate that they are generally pleased with it, with 32 positive comments compared

to 25 negative comments. Past users of CDA and/or CRA, not surprisingly, had more negative comments about the techniques than positive ones, with 13 positive to 22 negative responses. Perhaps one of the more interesting results of these evaluations of CDA and CRA were the responses by those who had never used CDA or CRA. These individuals were overwhelmingly negative about CDA and/or CRA. There were only 26 positive comments, and 110 negative comments. These results, along with the others discussed previously, lead one to believe that the most strenuous resistance to using CDA and CRA comes from those who know the least about them. This state of affairs can only be changed by large-scale educational efforts, tempered by the knowledge that almost half of the people who need the information have said that they have no desire for more information.

V Summary and Conclusions

Summary of Aerospace Usage

Almost twenty years have passed since the first uses of network management systems. These first networks, PERT and CPM, have undergone some evolutionary changes in that time, and are now perceived by some authors and managers as only slight variations on the same central technique, in this paper called PERT/CPM. During this period, various supplemental analytical techniques have been proposed and/or used with the basic network techniques. These supplemental techniques have been called many things, but perhaps most descriptively Cost Duration Analysis (CDA) and Critical Resource Analysis (CRA). Another network technique related to PERT but based on a work breakdown structure rather than activity times was developed, called PERT/COST. Despite basic structural and mathematical differences, CDA and CRA seem to have been associated with PERT/COST, possibly to the detriment of CDA and CRA.

The literature of the fields using these techniques is quite well stacked with theoretical and mathematical treatments of PERT/CPM, CDA, and CRA. Documentation of the application of these techniques, on the other hand, is sparse. In order to investigate the use of PERT/CPM, CDA and CRA in the aerospace industry, 114 organizations were contacted, 48 from the military and 66 from private industry. Data was gathered from 105 of these organizations, and this information was analyzed to determine the extent of the actual application of PERT/CPM, CDA, and CRA.

PERT/CPM Usage. Table 1 shows the results of contacts with the potential PERT/CPM users. Military use was 38 percent, which was slightly lower than the 47 percent for industry. For the whole sample including PERT/CPM Vendors, the use rate was 46 percent. Industry had a substantial lead over the Air Force in experience with PERT/CPM, presumably the result of personnel turnover of Air Force managers. The Air Force, however, had a lead in the amount of college training of its PERT/CPM users. All Air Force organizations had a PERT/CPM program available, but three individuals chose to use a manual network. In industry, there were also three individuals using manual networks when computers were available, but also eight others who had no PERT/CPM program and/or computer available. This made a total of 11 or 46 percent of industrial users of PERT/CPM using a manual network. An evaluation of the planning usefulness versus controlling usefulness of PERT/CPM was made by 53 of the 57 persons interviewed. The six PERT/CPM Vendors interviewed were excluded because of bias. On a one to nine scale with one being the worst and nine the best, planning usefulness got a mean score of 8.3, while controlling usefulness, on the same scale, got a mean of 6.3.

CDA and CRA Usage. CDA and CRA were both found to have a step halfway toward the full CDA or CRA technique. For CDA this analysis was called cost tracking, while for CRA it was called manpower loading. Of current users of PERT/CPM, four or 9.3 percent are now using CDA. An additional six are using cost tracking. Two CDA programs and three cost tracking computer programs are available in the Air Force, but are not being used. In an evaluation of CDA, complexity and cost were

cited as reasons for non-use most often, while those using it most often said it was fast and accurate.

There are only three individuals, for 7 percent of the current PERT/CPM users, who are currently using CRA. Six others are using manpower loading. One CRA program and three manpower loading programs were available to Air Force managers but were not being used. An evaluation of CRA by those interviewed yielded about the same results as CDA, with complexity and cost again the leading reasons for not using the technique. For both CDA and CRA, most of the resistance to the techniques came from those who had not used them.

Conclusions

The organizations interviewed are believed to be a fair sample of the aerospace industry, both military and civilian. Nonetheless, drawing absolute conclusions about such a large industry from a sample of 105 organizations would be hazardous at best. Rather, the following should be taken as reasonably possible interpretations of what may in fact be true.

PERT/CPM. There has been some speculation that PERT has undergone some sort of change in managers' minds since it was first introduced in the early 1960's. The evidence gathered in this research shows that PERT/CPM is being used in slightly less than half of the organizations in the aerospace industry. This can be compared to only four of thirteen Air Force program offices using PERT/CPM in 1974 (Ref 14:67). This indicates a considerable degree of acceptance and success over a 20 year period. Also, PERT and CPM may have blended, but the marriage

appears to have been beneficial, with the best of both remaining in today's large complex network management systems like IBM's PMS IV. The data gathered also indicated a perception of PERT/CPM as most beneficial as a planning tool, which may be limiting further applications by some managers.

CDA and CRA. Originally associated with CPM, these methods became associated with PERT and, at least in the minds of some managers, with PERT/COST. Neither appears to be very much in use in the aerospace industry. Perhaps they simply are perceived as not needed, or perhaps they have suffered from the perceived association with PERT/COST. Evaluations of CDA and CRA by those interviewed demonstrate that another reason for the small use rate of these methods is the complexity and cost of implementation.

The promise that techniques to facilitate making trade-offs among resources are not needed is hard to believe. Today, more than ever, resources of all kinds are extremely important. When PERT was first instituted in the military acquisition field, time was paramount. The continued security of the country depended on rapid completion of several projects. In today's military acquisition climate, however, emphasis is on cost, and getting more for the dollars spent. CDA and CRA are techniques which are aimed specifically at minimizing costs or efficiently using resources, and so should be of more and more importance as time goes on. The fact that there is a solid theoretical base for these techniques is a positive factor. Computer programs implementing these techniques are also available, but may lack some refinements simply because they have not had the benefit of much use. Apparently a good

many managers are concluding that the costs (in terms of personnel, time and data gathering) of implementing these resource-oriented management systems are not balanced by the benefits gained.

Recommendations

In order for managers to implement any system, they must perceive that it will benefit them to do so. The evidence gathered in this research indicates that most managers do not perceive CDA or CRA in that light. A policy by the government of forcing methods like these on contractors will not work. An educational program for contractors can have only limited success, since almost half of those interviewed expressed no desire for further information about CDA and CRA. In industry, economic incentives must exist for use of methods like these, and incentives could be provided by the government in the form of contractual requirements for time-cost tradeoff studies and the use of resource allocation procedures. These techniques may have the potential to save the government money in the long run, and closer studies of their application, in government and industry, are certainly warranted.

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35. Speeri, R. K., et al. A Statistical Procedure for Optimization of PERT Network Scheduling Systems. Technical Report No. 53. College Station, Texas: Texas A&M University, April 1976. (AD A025022).

36. "The PERT/COST System." Special Projects Office, Washington, D. C.: Navy Department, 1961.

37. Thompson, Charles V. A Case Study of Program Evaluation and Review Technique as Applied to the Compressor Research Facility Program. MS Thesis. Wright-Patterson AFB, Ohio: Air Force Institute of Technology, December 1975. (AD 020362).

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39. USAF PERT Volume II, PERT TIME Computer Handbook. Washington: Department of the Air Force, 1963.

40. USAF PERT Volume III, PERT COST System Description Manual. Washington: Department of the Air Force, 1963.

41. USAF PERT Volume IV, PERT COST Computer Program Handbook. Washington: Department of the Air Force, 1964.

42. USAF PERT Volume V, PERT Implementation Manual. Washington: Department of the Air Force, 1964.

43. Users Manual - Stochastic Network Analysis Program (SNAP). Huntingdon Valley, Pennsylvania: Computer Sciences Corporation (CSC), April 1978.

44. Welst, J. "Heuristic Programs for Decision Making." Harvard Business Review, 44:129-143 (September-October 1966).

APPENDIX A

Organizations Contacted

Appendix A

Organizations Contacted

Private Industry

1. Allied Technology Inc., Dayton, Ohio.
2. AMF Electrosystems, AMF Inc., Vandalia, Ohio.
3. ATC Inc., Dayton, Ohio.
4. Auto-Valve, Inc., Dayton, Ohio.
5. AVCO Corp., Wilmington, Massachusetts.
6. Bendix Corp., Avionics Division, Dayton, Ohio.
7. Bendix Corp., Communications Division, Baltimore, Maryland.
8. Boeing Co., Seattle Division, Seattle, Washington.
9. Centro Corp., Dayton, Ohio.
10. Elano Enterprises, Xenia, Ohio.
11. E-Systems Inc., Dallas, Texas.
12. Garrat Corp., Phoenix, Arizona.
13. Gayston Corp., Dayton, Ohio.
14. General Dynamics Inc., Fort Worth, Texas.
15. General Electric Corp., Aerospace Electronic Systems, Utica, New York.
16. General Motors Corp., Detroit Diesel Allison Division, Dayton, Ohio.
17. Goodyear Aerospace Corp., Akron, Ohio.
18. Grumman Aerospace Corp., Dayton, Ohio.
19. Grumman Aerospace Corp., Bethpage, New York.
20. GTE Sylvania Inc., Dayton, Ohio.

21. Hobart Brothers Company, Troy, Ohio.

22. Honeywell Inc., Avionics Division, St. Petersburg, Florida.

23. Hughes Aircraft Company, Culver City, California.

24. Hyland Machine Company, Dayton, Ohio.

25. Lear Siegler Inc., Instrument Astronics Division, Grand Rapids, Michigan.

26. Litton Systems Inc., Guidance and Control Systems Division, Dayton, Ohio.

27. Lockheed Aircraft Corp., Space and Missile Systems Group, Sunnyvale, California.

28. Lockheed Aircraft Corp., Missile Systems Division, Sunnyvale, California.

29. Marquart Company, Dayton, Ohio.

30. Martin Marietta Aerospace, Dayton, Ohio.

31. McCauley Accessory Division, Cessna Aircraft Company, Dayton, Ohio.

32. McDonnell Douglas Corp., Dayton, Ohio

33. Monsanto Research Corp., Mound Laboratory, Miamisburg, Ohio.

34. Norden United Technology Corp., Norwalk, Connecticut.

35. Northrup Corp., Hawthorne, California.

36. Parker-Hannifin Corp., Irvine, California.

37. Palmac Systems Inc., Dayton, Ohio.

38. Pratt and Whitney Division, United Aircraft Corp., Dayton, Ohio.

39. Projects Unlimited, Inc., Dayton, Ohio.

40. Raytheon Company, Missile Division, Bedford, Massachusetts.

41. Rockwell International, Anaheim, California.

42. Rohr Industries, Chula Vista, California.

43. Singer Company, Simulation Products Division, Dayton, Ohio.

44. Singer Company, Kearfott Division, Little Falls, New Jersey.

45. Sperry Rand Corp., Sperry Flight Systems Division, Phoenix, Arizona.

46. Sperry Rand Corp., Sperry Division, Sperry Systems Management, Great Neck, New York.

47. Sperry Univac Company, Defense Systems Division, Salt Lake City, Utah.

48. Sundstrand Corp., Dayton, Ohio.

49. Systems Development Corp., Santa Monica, California.

50. Systems Research Laboratory, Computer Sciences Group, Dayton, Ohio.

51. Tech Development Inc., Dayton, Ohio.

52. Technology Inc., Instruments and Controls Division, Dayton, Ohio.

53. Technology Inc., Technology-Scientific Services, Dayton, Ohio.

54. Teledyne Ryan Aeronautical, San Diego, California.

55. Teledyne CAE, Dayton, Ohio.

56. Teledyne Systems Company, Teledyne Inc., Northridge, California.

57. TRW Corp., Defense and Space Systems Group, Redondo Beach, California.

58. United Aircraft Products, Inc., Vandalia, Ohio.

59. Vought Corp., Vought Aircraft Division, Dallas, Texas.

60. Williams Research Corp., Walled Lake, Michigan.

Military

Air Force Audit Agency (AFAA)

ASD Audit Office, WPAFB.

Air Force Logistics Command (AFLC)

Air Force Acquisition Logistics Division (AFALD), WPAFB.

Air Force Systems Command (AFSC)

Aeronautical Systems Division (ASD), WPAFB.

Aeronautical Equipment SPO (AE)

Airlift SPO (SD28)

AMST SPO (SD29)

A-10 SPO (YX)

Comptroller (AC)

EF-111A SPO (SD25)

Fighter/Attack SPO (SD27)

F-15 SPO (YF)

F-16 SPO (YP)

International Fighter SPO (SD5)

Maverick SPO (SD65)

PLS/RPV SPO (SD26/31)

PRAM Office (RA)

Propulsion SPO (YZ)

Simulator SPO (SD24)

Specialized Systems (SDX)

Strategic Systems SPO (YY)

6570th Aerospace Medical Research Laboratory, WPAFB.

Air Force Human Resources Laboratory, WPAFB.

Air Force Wright Aeronautical Laboratories, WPAFB.

Aeropropulsion Laboratory

Flight Dynamics Laboratory

Materials Laboratory

Electronic Systems Division (ESD), Hanscom AFB

JTIDS Office

TRITAC Office

AWACS (E-3A) SPO

Airborne Command Post (E-4) SPO

Surveillance and Navigation SPO

Comptroller

Space and Missile Systems Organization, Los Angeles AFS.

Advanced Space Programs

Navstar GPS SPO

Launch Vehicles SPO

Re-entry Systems

Satellite Data Systems

Space Communications Systems

U. S. Army Corps of Engineers

Lima Area Office, Lima Modification Center, Lima, Ohio

PERT/CPM Vendors

Program Control Corporation

A-10 SPO, WPAFB

NAS, China Lake, California

PCC Office, WPAFB

On-Line Systems Inc., Los Angeles, California.

Computer Sciences Corp., Huntingdon Valley, Pensylvania.

APPENDIX B

Persons Interviewed

Appendix B

Persons Interviewed

1. Avlon, Ed. Boeing Company, ALCM Program. Seattle, Washington. Regarded by Boeing as the company expert on PERT.

2. Bates, Charles. 6570th Aeromedical Research Laboratory, Human Engineering Division. WPAFB, Ohio.

3. Baush, Jim. General Dynamics Inc., Management Support Group. Ft. Worth, Texas.

4. Bible, Richard. Airborne Command Post (E-4) SPO (ESD/YSM), Business Management Division. Hanscom AFB, Massachusetts.

5. Bitter, Steve and Bill Perry. Singer Company, Kearfott Division, F-16 Assistant Program Director and Director of Management Support. Little Falls, New Jersey.

6. Boenning, Charles. Allied Technology Inc., Director of Engineering. Dayton, Ohio.

7. Bosinger, Al. Sperry Rand Corp., Sperry Division, Sperry Systems Management, Programs. Great Neck, New York.

8. Brewer, Larry. ASD Comptroller's Office, Directorate of Program Control. WPAFB, Ohio.

9. Brown, Roger. U. S. Army Corps of Engineers, Lima Area Office, Lima Modification Center, Project Engineer. Lima, Ohio.

10. Bush, Chan. Vought Corp., Vought Aircraft Division, Engineering Administration and Management. Dallas, Texas.

11. Crews, Ron. Air Force Audit Agency, ASD Audit Office, WPAFB, Ohio.

12. Davis, Bill. Program Control Corporation, WPAFB Representative. WPAFB, Ohio.

13. Dietrich, Walt. Simulator SPO (ASD/SM24PF). Financial Management Branch. WPAFB, Ohio.

14. Duscommun, Carol. On-Line Systems Inc., Marketing Representative. Los Angeles, California.

15. Elder, Paul. PLS/RPV SPO (ASD/SD26P), Program Control. WPAFB, Ohio.

16. Fickef, Jay. Systems Research Laboratories Inc., Computer Sciences Group, Computer Applications Division. Dayton, Ohio.

17. Foster, William. Space Communications Systems (SAMSO/SKP), Director of Program Control. Los Angeles AFS, California.

18. Fout, Bruce. Hobart Brothers Company, Troy Division, Engineering. Troy, Ohio.

19. Gibson, Jim. Launch Vehicles SPO (SAMSO/LVP), Program Control. Los Angeles AFS, California.

20. Hardy, Larry. Sundstrand Corp., Dayton Office. Dayton, Ohio.

21. Harris, Nick. United Aircraft Products Inc., President. Vandalia, Ohio.

22. Hassler, Bob. Lockheed Aircraft Corp., Space and Missile Systems Group, Chief of Information Processing. Sunnyvale, California.

23. Hefernon, Reginald. Goodyear Aerospace Corp., Chief of Program Control and Planning. Akron, Ohio.

24. Hendrixson, Jerry. Concord Industries Inc., President. Los Angeles, California.

25. Himmelmann, Carl. Grumman Aerospace Corp., Resource Department, Plans, Controls and Budgets Division, Master Schedule Section. Bethpage, New York.

26. Hogden, Vernon. Air Force Wright Aeronautical Laboratories, History Office. WPAFB, Ohio.

27. Johnson, Ray. Technology Inc., Instruments and Controls Division. Dayton, Ohio.

28. Judson, David. Air Force Materials Laboratory, Manufacturing Technology Division, Metals Branch. WPAFB, Ohio.

29. Klein, John. General Electric Corp., Aerospace Electronic Systems, Chief of Programs, Plans and Controls. Utica, New York.

30. Kovacs, Sam. Strategic Systems SPO (ASD/YYPF), Financial Management Division. WPAFB, Ohio.

31. LeClaire, Richard. KC-10 SPO (AFALD/YTFX), Plans and Programming Division. WPAFB, Ohio.

32. Loews, Jim. Parker-Hannifin Corp., Engineering Division. Irvine, California.

33. MacElroy, Joe. System Development Corp., Estimation and Price Development Group. Santa Monica, California.

34. Mason, Will. ESD Comptroller's Office (ESD/ACBB), Business Management Division. Hanscom AFB, Massachusetts.

35. Miller, Bob. TRW Corp., Defense and Space Systems Group, Programs. Redondo Beach, California.

36. Miles, Ross. F-16 SPO (ASD/YPEX), Analysis and Integration Division. WPAFB, Ohio.

37. Mitchel, Walker and Donald Schmidt. Air Force Aero Propulsion Laboratory, Technical Facilities Division, Compressor Research Facility Acquisition. WPAFB, Ohio.

38. Nydeger, John. F-16 SPO (ASD/YPEX), Analysis and Integration Division. WPAFB, Ohio.

39. Perion, David. Technology Inc., Technology-Scientific Services, Project Management Branch, Computer Systems Section. Dayton, Ohio.

40. Price, Jim. Program Control Corporation, A-10 SPO. WPAFB, Ohio.

41. Pumroy, Fred. Strategic Systems SPO (ASD/YYP), Program Control. WPAFB, Ohio.

42. Reese, Vince. Sperry Univac Company, Defense Systems Division, Configuration Management. Salt Lake City, Utah.

43. Reeves, Jerry. Teledyne Inc., Teledyne Systems Company, Program Management. Northridge, California.

44. Regan, Dick. Raytheon Company, Missile Division. Bedford, Massachusetts.

45. Riedeger, Doug. Maverick SPO (ASD/SD65P), Program Control. WPAFB, Ohio.

46. Robertson, John. Program Control Corporation, NAS China Lake. China Lake, California.

47. Robins, Frank. Lockheed Aircraft Corp., Missile Systems Division. Sunnyvale, California.

48. Russell, Thad. JTIDS SPO (ESD/DCBX), Business Management Office. Hanscom AFB, Massachusetts.

49. Schugart, Rex. Lear Siegler Inc., Instrument Astronics Division. Grand Rapids, Michigan.

50. Seela, Don. EF-111A SPO (ASD/SD25P), Program Control. WPAFB, Ohio.

51. Spencer, Chuck. Grumman Aerospace Corp., Dayton Office. Dayton, Ohio.

52. Swanks, Julia and Mike Durieko. Air Force Flight Dynamics Laboratory, Financial Management and Computer Services. WPAFB, Ohio.

53. Taylor, Donald. Computer Sciences Corp., Defense Systems Division, Combat Data Systems Center, Operations Manager. Huntingdon Valley, Pennsylvania.

54. Triscari, Tom. Airlift SPO (ASD/SD28P), Program Control. WPAFB, Ohio.

55. Tyson, Barry. Garret Corp., Dayton Office. Dayton, Ohio.

56. Wilber, Joe. Bendix Corp., Communications Division, Engineering Directorate. Baltimore, Maryland.

57. Yonko, Jon. Monsanto Research Corp., Mound Laboratory. Miamisburg, Ohio.

APPENDIX C

Sample Interview Format

Appendix C

Sample Interview Format

PERT/CDA/CRA Usage Scale (Scale A)

(0) I have never heard of it before.

(1) I have heard of it in passing, know what it is, but do not know any details about it.

(2) I have talked to others or read a fair amount about it, but need to investigate further to determine if I can use it.

(3) I have found out all I need to know about it, and presently it is not suitable for use in my operation.

(4) I have found out all I need to know about it, and I will probably use it in the future.

(5) I have used it in the past, but no longer do.

(6) I am currently using it as a management tool.

PERT Planning/Controlling Usefulness Scale (Scale B)

(1) Worst I have used or seen used

(2) A little better than the worst

(3) Better than the worst

(4) Not quite as good as others

(5) About the same as others

(6) A little better than others

(7) Better than others

(8) Not quite the best

(9) The best I have used or seen used

Sample Interview

Name:
Organization:
Phone:
Date:

To what extent are you acquainted with network management?
a. 0 1 2 3 4 5 6 (Scale A)
b. Name used: PERT CPM Other _____

How long has PERT been used:
a. Personally _____years
b. Organization _____years

Have you had any formal training in PERT, including formal courses given by your organization?
a. College Post-grad Organization
b. Time spent on PERT? _____weeks
c. When last course completed _____weeks
d. Is course still being offered? yes no uncertain

Do you have computer support available to you?
yes no uncertain
a. Is a PERT program available? yes no uncertain
b. If so, are you using it? yes no

What is your opinion about PERT as a means of planning (and replanning) a project, compared to other methods you have used? (examples: regular staff meetings; budgets; checklists; milestones; standard planning outlines) (Scale B)

1	2	3	4	5	6	7	8	9
the worst I have used				about the same as the others				the best I have used

What is your opinion about PERT as a means of scheduling and controlling a project after all planning (and replanning) has been done, compared to other methods you have used? (examples: regular staff meetings; bar (Gantt) charts; milestone charts; line of balance; linear programming; trouble shooting problems only; management by exception) (Scale B)

1	2	3	4	5	6	7	8	9
the worst I have used				about the same as the others				the best I have used

To what extent are you acquainted with Cost-Duration Analysis?
a. 0 1 2 3 4 5 6 (Scale A)

If available, does your computer program for PERT have an option for solution of Cost-Duration problems?
not available yes no uncertain

(0) I HAVE NEVER HEARD OF CDA BEFORE.

Do you think someone else in your organization may have heard of it?

(1) I HAVE HEARD OF CDA IN PASSING, KNOW WHAT IT IS, BUT DO NOT KNOW ANY DETAILS ABOUT IT.

1. Where did you hear about it?
Under what circumstances?
When?

2. From what you know about it, do you think it could work for you?
Why? (or why not?)

3. Before you talked to me, had you intended to look into it further?

(2) I HAVE TALKED TO OTHERS, OR READ A FAIR AMOUNT ABOUT CDA, BUT NEED TO INVESTIGATE FURTHER TO DETERMINE IF I CAN USE IT.

1. Where did you learn about it?
When?

2. From what you know about it, what may be some benefits of using it?
Do you foresee any problems with it?

3. Do you lean one way or another about using it?

(3) I HAVE FOUND OUT ALL I NEED TO KNOW ABOUT CDA, AND PRESENTLY IT IS NOT SUITABLE FOR USE IN MY OPERATION.

1. Where did you first learn about it?
Under what circumstances?
When?
When was the last time you heard (or read) anything about it?

2. What is there about it that you find unsuitable?
   Were there other factors which entered into your decision?
   Which of these factors influenced you the most?
   Were you aware of some positive factors?

3. Do you think this technique could be used by other organizations in the aerospace industry?
   Are you aware of anyone who is?
   What are the major differences between them and your organization, that they can use it?

4. Do you think you may someday reconsider, especially if some of the problem areas could be eliminated?

(4) I HAVE FOUND OUT ALL I NEED TO KNOW ABOUT CDA, AND WILL PROBABLY USE IT IN THE FUTURE.

1. Where did you first learn about it?
   Under what circumstances?
   When?
   When did you last hear (or read) anything about it?

2. What benefits of using it were most influential in your decision to use it?
   What other thing does it do well?
   What problem areas can you foresee in using it?

3. Why are you not using this method now?

(5) I HAVE USED CDA IN THE PAST, BUT NO LONGER DO.

1. Where did you first learn about it?
   Under what circumstances?
   When?

2. How long has it been since you used it?
   Why did you stop using it?
   Have you read or heard anything about it since you last used it? ... anything new?

3. Was it useful to you while you were using it? How?
   How extensively did you use it?
   Do you plan to use it again? In the same format and methods?

4. What type of method did you use? (Name or description).

5. Are you aware of other aerospace organizations which continue to use this technique successfully?
   If so, why can they use it and not you?

(6) I AM CURRENTLY USING CDA AS A MANAGEMENT TOOL.

1. Where did you first learn about it?
   Under what circumstances?
   When?
   Are you keeping up to date on improvements? How?
   When was the last time you heard or read about something new regarding it?

2. How extensively do you use it?
   Do you try to apply it on every project possible, or only if problems arise?

3. What aspect of the technique do you find the best?
   What are some areas that you feel are weak or need improvement?
   Have you had any problems with it?

4. What type of method are you using? (name or description).

5. Do you know of other Aerospace organizations which are using or have used it?
   Why do you think more organizations do not use it?

To what extent are you acquainted with Critical Resource Analysis?
a. 0 1 2 3 4 5 6 (Scale A)

If available, does your computer program for PERT have an option for the solution of Critical Resource problems?
not available yes no uncertain

(0) I HAVE NEVER HEARD OF CRA BEFORE.

1. Do you think someone else in your organization may have heard of it?

(1) I HAVE HEARD OF CRA IN PASSING, KNOW WHAT IT IS, BUT DO NOT KNOW ANY DETAILS ABOUT IT.

1. Where did you hear about it?
   Under what circumstances?
   When?

2. From what you know about it, do you think it could work for you?
   Why? (or why not?)

3. Before you talked to me, had you intended to look into it further?

(2) I HAVE TALKED TO OTHERS, OR READ A FAIR AMOUNT ABOUT CRA, BUT NEED TO INVESTIGATE FURTHER TO DETERMINE IF I CAN USE IT.

1. Where did you learn about it?
   When?

2. From what you know about it, what may be some benefits of using it?
   Do you foresee any problems with it?

3. Do you lean one way or another about using it?

(3) I HAVE FOUND OUT ALL I NEED TO KNOW ABOUT CRA, AND PRESENTLY IT IS NOT SUITABLE FOR USE IN MY OPERATION.

1. Where did you first learn about it?
   Under what circumstances?
   When?
   When was the last time you heard (or read) anything about it?

2. What is there about it that you find unsuitable?
   Were there other factors which entered into your decision?
   Which of these factors influenced you the most?
   Were you aware of some positive factors?

3. Do you think this technique could be used by other organizations in the aerospace industry?
   Are you aware of anyone who is?
   What are the major differences between them and your organization, that they can use it?

4. Do you think you may someday reconsider, especially if some of the problem areas could be eliminated?

(4) I HAVE FOUND OUT ALL I NEED TO KNOW ABOUT CRA, AND WILL PROBABLY USE IT IN THE FUTURE.

1. Where did you first learn about it?
   Under what circumstances?
   When?
   When did you last hear (or read) anything about it?

2. What benefits of using it were most influential in your decision to use it?
   What other thing does it do well?
   What problem areas can you foresee in using it?

3. Why are you not using this method now?

(5) I HAVE USED CRA IN THE PAST, BUT NO LONGER DO.

1. Where did you first learn about it?
   Under what circumstances?
   When?

2. How long has it been since you used it?
   Why did you stop using it?
   Have you read or heard anything about it since you last used it? ... anything new?

3. Was it useful to you while you were using it? How?
   How extensively did you use it?
   Do you plan to use it again? In the same format and methods?

4. What type of method did you use? (Name or description)

5. Are you aware of other Aerospace organizations which continue to use this technique successfully?
   If so, why can they use it and not you?

(6) I AM CURRENTLY USING CRA AS A MANAGEMENT TOOL.

1. Where did you first learn about it?
   Under what circumstances?
   When?
   Are you keeping up to date on improvements? How?
   When was the last time you heard or read about something new regarding it?

2. How extensively do you use it?
   Do you try to apply it on every project possible, or only if problems arise?

3. What aspect of the technique do you find the best?
   What are some areas that you feel are weak or need improvement?
   Have you had any problems with it?

4. What type of method are you using? (name and description)

5. Do you know of other Aerospace organizations which are using or have used it?
   Why do you think more organizations do not use it?

VITA

Lawrence J. Klementowski was born in Lackawanna, New York on April 10, 1949. He graduated from high school in Athol Springs, New York in 1967 and attended the State University of New York at Buffalo from which he graduated in 1971 with a Bachelor's degree in Chemical Engineering and a commission in the United States Air Force.

After completing pilot training at Williams Air Force Base, Arizona, he flew the C-9A Nightingale at Scott Air Force Base, Illinois. In March 1976 he completed Squadron Officer School in residence at Maxwell Air Force Base, Alabama, and was assigned to the Scott Command Post. While serving there as a Wing Officer Controller, he continued to fly the aeromedical airlift mission in the C-9A. He entered the Air Force Institute of Technology in June, 1977.

He is married to the former Julianne A. White of Yonkers, New York. They have two daughters, Carissa Louise and Kimberly Meredith.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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CPM	Networking
PERT/COST	Network Management
Cost Duration Analysis	Aerospace Acquisition
Critical Resource Analysis	Weapon System Acquisition

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The rapid pace of technological progress in the last 75 years has caused the development of a number of new management tools, but perhaps the most controversial of these is network based management. Two closely related methods exist, the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). These methods are often spoken of today as one, called PERT/CPM. Two important analytical techniques often used with PERT/CPM are Cost Duration Analysis (CDA) and Critical Resource Analysis (CRA). →

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Continuation
Block 20. ABSTRACT

PERT, CPM, CDA, and CRA have gone through many changes since they were developed in the late 1950's, and the current theoretical and mathematical approaches to them can be quite complex. This theory tends to dominate published material in the network management field, there being little documentation of practical applications of PERT/CPM. This disparity was investigated in the aerospace industry in this thesis.

Contacts were made with 114 organizations, 48 military and 66 private industry. Information was received from 105, and of these, 48 were using some form of PERT/CPM. In the military, 38 percent were using PERT/CPM; while in industry it was 47 percent. There was a significant discrepancy in the experience levels between Air Force and industry, with the industry having considerably more experience. The use rates for CDA and CRA were found to be quite low, with only 9.3 percent and 7 percent, respectively, of current PERT/CPM users reporting the use of these techniques. Individuals interviewed were asked to evaluate CDA and CRA, and it was found that the most often mentioned reasons for not using CDA and CRA were their complexity and cost.